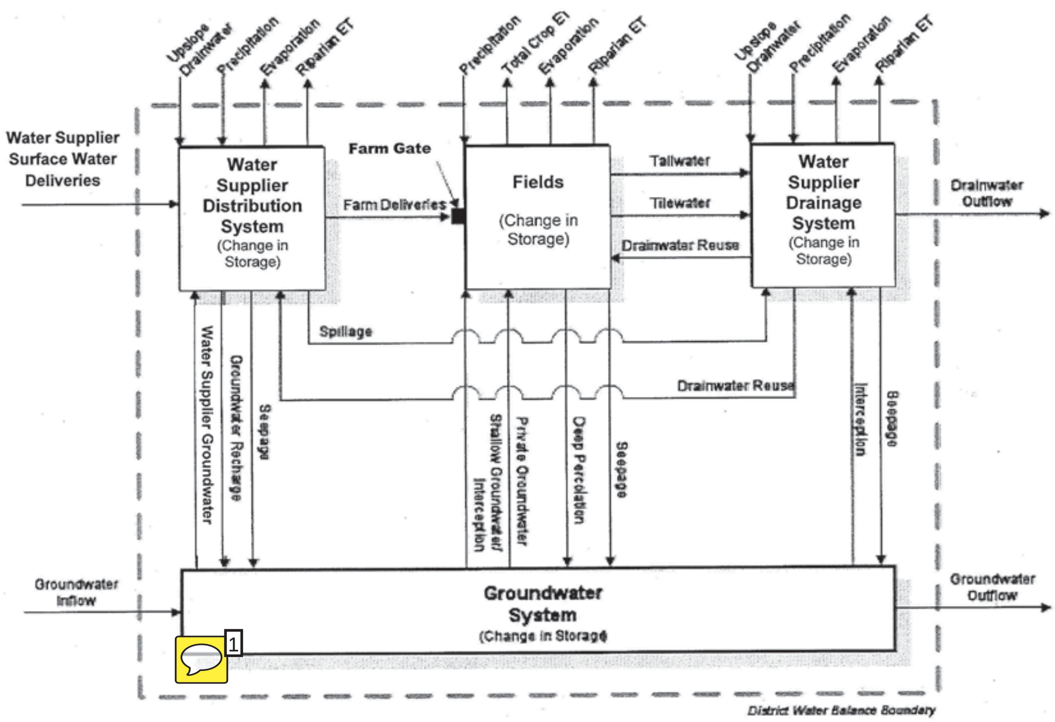
3 Methodology for Quantifying the Efficiency of Agricultural Water Use

The quantification of water use efficiency needs to recognize and consider the fate of water at different spatial levels. The water balance discussed here provides a useful framework for understanding and quantifying agricultural water use efficiency. Measurement and quantification of all the water balance components, such as parsing evaporation and transpiration into its parts, is a technical challenge; therefore, the components of the water balance used in this report to quantify the efficiency of agricultural water use are the components of the water balance that can be measured or quantified using models.

3.1 Spatial Scales Considered

For purposes of developing a methodology, DWR considered the following spatial scales that closely align with fields, delivery systems, and basin water management (Figure 3-1).



Source: Water Management Planner, Bureau of Reclamation, October 2000 (Modified)

Figure note: Crop ET is crop evapotranspiration, Riparian ET is ebvapotranspiration by vegetation, weeds, and phreatophytes, Evaporation is loss of water from surface of water or soils, Tailwater is runoff from fields, and Tilewater is the drainage flow captured from drains. Seepage is outflow of water from canals or reservoirs and Deep Percolation is downward flow of water into groundwater.

Figure 3-1 Schematic diagram of water supplier scale water balance

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There is no "salt sink" consumptive use in this figure. This is a big oversight for a figure showing "tilewater" flows. Since most drainage tile in the state is for saline water and not just high water table.

commonly used approach for estimating ET is to use reference evapotranspiration (ETo) and crop coefficients (Kc), as described by DWR California Irrigation Management Information System (CIMIS) (http://wwwcimis.water.ca.gov/cimis/welcome.jsp). Other equivalent methods are also used. 1 2

Equation 1-B

$$ET = Kc * ETo$$

- **Effective precipitation (Pe)** is the fraction of precipitation water that is available for crops to use. Since a part of the precipitation becomes runoff, deep percolation, and evaporation, only a fraction of the total precipitation is available to satisfy crop water needs. Pe depends on many factors including the slope of the land, soil type, soil moisture content, rainfall characteristics, weather conditions, and plant type. It is highly recommended that the method used has proven accuracy for estimating Pe for the area of interest. A soil moisture balance might be needed to determine with less uncertainty how much precipitation is available for crop uptake . This is especially important in higher precipitation zones, such as the Sacramento Valley, where higher precipitation values do not always contribute to higher soil moisture storage for crop uptake. See Appendix D for additional information and references for estimating Pe.

- **Applied water (AW)** is the total volume of water that is applied to field(s) within an area (field, supplier, or basin) to meet the crop evapotranspiration, agronomic, and environmental use from any source, surface water (including tailwater reuse) or groundwater, public or private, including initial soil moisture in the soil profile that is not from precipitation. Unique values at each spatial scale include:
  - **Field scale applied water (AWf)** is quantity of water derived from supplier's surface or groundwater measured deliveries (adjustments are needed if the entire delivery is not applied to the field) and private groundwater pumping. Alternatively, AWf at the field may be measured with a water measurement device.
  - **Water supplier scale applied water (AWs)** is quantity of water derived from supplier's measured surface or groundwater deliveries and private groundwater pumping within the supplier's service area. Water used for non-agricultural crop and non-environmental uses within the supplier's boundary [Municipal and Industrial (M&I), dairy production areas, etc.] are excluded.
  - **Basin scale applied water (AWb)** is quantity of water derived from all supplier's measured surface or groundwater deliveries and private groundwater pumping in the basin. Water used for non-agricultural

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This calculation is dependant on the accuracy of the Kc values used for specific crops and field conditions. Older published values of Kc may not accurately reflect the true crop ET and production potential of newer varieties, planting strategies and management. For example, a recently completed four year study of almond ET in Kern, Fresno, Butte and Tehema Counties by the Uniiversity of California measured mid-summer Kc values in micropsprinkler irrigated almonds that were 25% higher than previously published values (Sanden, et. al., 2012).

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Reference to above:

Sanden, B.L. A.E. Fulton, D.S. Munk, S. Ewert, C. Little, F. Anderson, J.H. Connell, M.D. Rivera, M. Orang and R.L. Snyder. 2012. California's Effort to Improve Almond Orchard Crop Coefficients. European Geosciences Union General Assembly 2012, Vienna, Austria, 22–27 April, 2012, Session SSS11.3:Soil and irrigation sustainability practices. Abstract EGU2012-7043.

This paper will actually be delivered this Wednesday in Vienna by Rick Snyder. We do not yet have a web address for the repository of the abstracts. A revised almond ET/Kc UC Extension Bulletin is planned for this fall, which will be the best reference.

crop and non-environmental uses within the basin boundary (M&I, dairy production areas, etc.) are excluded.

- **County scale applied water (AWc)** is quantity of water derived from suppliers and groundwater pumping within a county. This value may be estimated by interpolation. Water used for non-agricultural crop and non-environmental uses within the county (M&I, dairy production areas, etc.) are excluded.

Method 2: Agronomic Water Use Fraction (AWUF). *Purpose:* It quantifies the efficiency of water use for the purpose of crop evapotranspiration and agronomic use. It allows for evaluation of the relationship between the crop use, agronomic use of a crop and the quantity of water applied to an area. Method 2 is recommended for field, water supplier, and basin scales.

Method 2 allows for evaluation of the relationship between the agronomic use of a crop and the quantity of water applied to an area.

AWUF is calculated with the equation

Equation 2

AWUF= [ETAW+AU]/AW, where

AU is agronomic use in inches or acre feet per year

- **Agronomic use (AU)** is the portion of applied water directed to produce a desired agricultural commodity, such as water applied for salinity management or frost control, decomposition, and other water applications essential for production of crops.
  - **Leaching requirement (LR**) is the minimum leaching fraction (LF) that is required over a growing season for a particular quality of water to achieve maximum yield of a given crop (Letey et al., 2011). LF is the fraction of the total applied water that drains below the plant root zone. LR is used to estimate the amount of water needed to leach out excess salts from the root zone and create an optimum condition for crop production. It is the minimum LF that corresponds to the maximum salinity level that a specific **crop** can tolerate. LR is estimated using the ratio of the electrical conductivities of irrigation water and drainage water.

AWUF - agronomic water use fraction
AU - agronomic use
LF – leaching fraction
LR - leaching requirements

Equation 2-A

(LR= ECiw/ECdw), where

ECiw is the electrical conductivity of irrigation water (decisiemens per meter-dS/m), and ECdw is the electrical conductivity of drainage water (dS/m). Decisiemens is a measure of electric conductance.

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desired

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determined by the salt tolerance of that crop

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in a solution

In some cases, it may be difficult to determine the exact location of the root zone depth and take measurements of the electrical conductivities of drainage water. Under such circumstances, alternative methods can be utilized to estimate leaching requirement. Studies have shown, for example, that ECdw can be accurately estimated from the electrical conductivities of root zone saturation extract and irrigation water (Rhoades, 1974). According to Rhoades (1974),

ECdw=5ECe-ECiw,

where ECe is the average electrical conductivity of the saturation extract in the root zone and ECiw is the electrical conductivity of irrigation water. 1 ~~LR can, therefore, be estimated from~~

ECe can either be measured at different depths within the root zone, and average values calculated, or estimated from salinity tolerances of various crops. The Food and Agriculture Organization of the United Nations (FAO-UN) publication paper #29 (Ayers and Westcot, 1994) lists the salt tolerance data for various crops. ECe values can, therefore, be obtained from Table 4 of the FAO publication or other published works. See Appendix D for crop salt tolerances and yield potential. 2

Equation 2-B

LR= ECiw /[(5 x ECe) – Eciw], where

ECe is the crop salt tolerance threshold at no yield reduction.

The amount of water required to remove salts from the root zone area is estimated using the ratio of the electrical conductivities of irrigation water (ECiw) and drainage water ECdw.

LR = ECiw/ECdw

Water in excess of the leaching requirement that goes to deep percolation would reduce water use efficiency at that scale. It should be noted, however, that due to uncertainties in quantifying leaching requirements and due to low distribution uniformities of applications, some amount of water in excess of leaching requirement may be reasonable.

- **Climate control** may require the use of some water for cooling of crops and frost protection. The amount of water used depends on crop type and weather parameters such as humidity and temperature. Application of water for climate control should start when temperature reaches critical thresholds for each crop and continued until the temperature becomes more favorable. Weather station networks such as CIMIS can provide the temperature and humidity data needed to determine when to turn sprinklers on and off. Although significant amount of water used for climate control may evaporate, the rest will infiltrate into the soil and become available for crops to

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LR can, therefore, be estimated using Equation 2-B.

4.2.2.3 Data Collection and Reporting Responsibility

DWR recommends that the field scale methods be implemented through a co-operative and voluntary irrigation evaluation program of self-enrolled growers. For suppliers equal or greater than 25,000 acres, field scale evaluations and calculations would be done through the on-farm irrigation evaluation programs that water supplier provides to its customers (as required by CWC section 10608.48 (d), if it is locally cost effective.

Mobile labs (teams of technicians with specialized equipment to perform irrigation evaluation) were established in California to perform activities such as DU and onsite irrigation system evaluation for efficiency. The evaluation takes one day to complete, covers an entire field evaluated, and includes standardized data collection and analysis. The primary field activities for evaluating DU and system efficiency are pressure measurements, flow rate measurements, and the determination of applied water.

- In an on-farm evaluation service provided on a voluntary basis to growers, the growers would be selected to provide a representative sample of fields by region, crop, irrigation system, and other appropriate factors. The data collected would be provided to the growers for making improvements in their water management practices. DWR has in the past funded irrigation system evaluation on a cost share arrangement with water suppliers. This can be a phased approach starting with supporting the existing irrigation system evaluations and potentially expanding to additional irrigation system evaluations (through mobile labs or similar venues) to provide a larger and more representative sample of fields. Protocols for confidentiality would be developed to ensure that information identifying individual fields, owners, or operators is not improperly disclosed. Collected data stripped of any personal or business information would be used by participating local and State agencies for improving local, regional, and statewide water management planning.
- Water suppliers and participating agencies develop summary of data including mean and standard deviation of field scale values of CCUF, AWUF, and TWUF and submit to DWR in AWMP.
- Existing National Resources Conservation Services (NRCS) and California Association of Resource Conservation Districts (CARCD) protocols for the irrigation system evaluation (mobile lab) activities be utilized.

For suppliers smaller than 25,000 acres, field scale evaluations would be done by water supplier or other cooperating entities if funding is available. DWR recommends:

- A cost share program in cooperation with interested entities. Potential entities may include the Agricultural Water Management Council, water suppliers, cooperating federal agencies, California Resource Conservation Districts, University of California Cooperative Extension, and other research institutions such as Cal Poly Training and Research Center or the Center for Irrigation Technology at California State University, Fresno or other entities to provide an irrigation and water use evaluation service, modeled on the irrigation system evaluation, to cooperating growers.

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Significant changes to current Mobile Lab protocols would be required to add a valid estimate of annual CCUF beyond the much simpler measurements needed for DU. This includes a much more extensive interview of the grower/foreman and access to their applied water records

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within the supplier scale

Table C-1 Water supplier scale water use efficiency quantification methods and Indicators, example 1

(see also Table C-3 for additional applicable details)

Quantifying the Efficiency of Agricultural Water Use and irrigation System Performance

<table>
<tr><th>Elements</th><th>Explanations</th><th>Calculations</th></tr>
<tr><td>ETAW</td><td>Evapotranspiration of applied water (ETAW) can be calculated as the seasonal total crop evapotranspiration (ET) minus the cumulative effective rainfall contribution (Pe), estimated assuming that 25 percent of total precipitation from January to the end of irrigation season contributes to ETc. Therefore, the total ETAW can be expressed as ETAW = (ET – Pe) X crop acreage.

In-season weighted mean crop coefficient curves (Kc) for a crop is used with the cumulative reference evapotranspiration (ETo) to determine total seasonal crop evapotranspiration, ET.

A sample calculation of a seasonal crop water balance for a tomato crop grown at Davis, California is shown below. A weighted mean Kc value of 0.82 for the periods of planting to harvest was used to represent tomato. For simplification, the values of Kc for the different periods within the growing season are represented as straight lines. The cumulative ETo value obtained from the CIMIS station at Davis for the cropping season is 2.92 ft.

ET = ETo X Weighted mean Kc = 2.92 X 0.82 = 2.40 ft

Pe = Total Precipitation X 20% = 1.15 X 20% = 0.23 ft

Crop acreage = 45,000 acre

Substituting these values in the proposed equation yields

ETAW= (ET-Pe)= (2.2-.23)=2.2

ETAW = (2.2) X 45,000 = 99,000 AF per year

Note- ETAW calculated above was compared with predictions of ETAW with the CUP plus application program “Consumptive Use Program Plus” or “daily soil water balance program” developed to estimate daily soil water balance to determine ETc and ETAW for agricultural crops and other surfaces that account for ET losses and water contributions of rainfall and irrigation water (see Appendix D). The calculations require input of weather or climate data, soil depth and water-holding capacity, crop root depth, and seasonal crop coefficient curves. Estimates of ETAW compared well with CUP plus; for example, the total ET estimates for tomato at Davis for 2010 were 2.40 ft and 2.5 of ET and Pe of 0.23 ft and 0.16 ft for this method and CUP plus respectively, a difference in ETAW value of roughly 6%.</td><td>ETAW= 2.2x45,000= 99,000 AF per year</td></tr>
<tr><td>Agronomic</td><td>Seasonal evapotranspiration of a tomato crop (ET) grown in Yolo County in 2010 is 2.4 ft. Electrical conductivity (ECi) of irrigation water is 1.0 ds/m. LR is calculated as:
$$LR = \frac{EC_i}{5(EC_e) - EC_i}$$
The ECe from Table D-1 for tomato at a 100 percent yield potential is 2.5 ds/m, therefore:
$$LR = \frac{1.1}{5(2.5) - 1.1} = 0.10$$
Agronomic Use (AU) can be estimates as:</td><td>AU = (0.10 X 2.2 X 45,000) = 9,900 AF per year</td></tr>
</table>

	AU = (LR X ETAW X crop acreage Substituting these values in the ab equation yields The AU is the amount of applied irrigation water needed to meet leaching requirement of a tomato crop grown in Yolo County in 2010.	
Environmental	Garter snake habitat maintained on canal banks; plants assumed to have ET = 4 AF/A (Sudan grass). Approximately 50 acres of habitat. Water use =ETxArea	Canal habitat: EU= 4x50= 200 AF per year
	Several fields are flooded in fall/winter to provide habitat for migratory birds. Approx 6-inches per acre of net water for 8,000 acres in supplier's boundary are used. Water use= ETxArea	Field habitat = (6/12)x 8,000=4,000 AF per year
	Supplier is required to maintain 6 cubic feet per second (cfs) flows in drain from June 1 through October 30 for habitat. Water use= (flow)x(Duration)= (6 cfs)(3600x24 sec/day)/(43,560 af/cf)(150 day)=1,800 AF	Drain flows = 1,800 AF per year Total EU= 200+4,000+ 1,800= 6,000 af per year
Aggregate Farm-gate Deliveries	Estimate provided by water supplier in monthly measured billings.	Aggregate farm-gate deliveries per year = 148,555 af/year
Recoverable Flows	This value is estimated using several sources of data and calculations:	-
	Using data from gauge on the drain (above).	Drain data = 1,800 AF per year
	It is estimated that 2 inches per acre of leaching requirements are deep percolation.	Estimated deep percolation from leaching = (2/12)(45,000)= 7,500 AF per year
	The remaining portion of the total delivered water that is not crop ET, agronomic water and environmental water is identified. =AW-ETAW-EU-AU	Estimated additional deep percolation (not from leaching) =160,920-99,000-9,900-6,000=46,020 af
	Based on the estimate of the acreage of non-cropped area , 20% is used by non-crop plants that are not part of intentional environmental objectives therefore, irrecoverable.	20%(46,020)= 9,204 af
	The portion remaining is considered returning as additional deep percolation to that from intentional leaching	80% (46,020) = 36,816 AF per year Total estimated recoverable flows = 1,800 + 7,500 + 36,816 = 46,116 AF/yr
Supplier Scale Water Supply and Applied Water	Quantity diverted by the supplier is derived from records for filing to the SWRCB. The supplier and privately pumped groundwater is estimated from power usage records.	Supplier diversions = 156,420 AF/yr Estimated GW pumped = 19,500 AF/yr. Total WS =175,920 AF
	Total deliveries to non-irrigation agriculture and M&I are subtracted from the total water supplies. Delivered water also excludes groundwater recharge and accounts for the net change in surface storage within the water supplier's boundaries. Initial soil moisture in soil profile is accounted for, 1000 af.	Supplier non-irrigation agricultural deliveries = 10,000 AF/yr Supplier M&I deliveries = 4,000 AF/yr Soil moisture 1,000 AF. Applied water per year = 175,920-10,000-4,000-1,000= 160,920 AF per year
Results		

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What happened to the stand establishment water needed for evaporation during germintion as AU. It is in the field example but not here.

C.1.3 Field Scale

To provide insight into the use of the methods at the field scale, the following example was developed. Under this example, the field consists of 125 acres of processing tomatoes; planted from seed in raised beds and furrow irrigated. The field scale deliveries are augmented with groundwater pumping and the net change in surface storage and soil moisture are accounted for. Using this example for a single growing season, each method is calculated at the field scale in Table C-3.

Table C-3 Field scale example of water use efficiency quantification methods and Irrigation System performance Indicator

Quantifying the Efficiency of Agricultural Water Use and Irrigation System Performance Indicator

Elements	Explanations	Calculations
ETAW	Similar to Example 1. See Table C-1 for details. ETo= 2.92 ft Kc=0.82 Pe=0.23 ft ET=ETOxKc Area= 125 acres ETAW= (ET-Pe)xArea	ET=2.92x0.82=2.4 ETAW=(2.4-0.23)x 125= 275 AF
Agronomic Use	Similar to example 1 assumptions. LR= 0.1 Area= 125 Acres ETAW= 2.2 AU= ((LR)(ETAW)(Area)=	LR = (0.1)(2.2)(12[illegible]7.5 AF per season Seed bed preparation= 17 AF per season Total = 44.5 AF per season (of this amount, 10 AF of the seed bed water doubles as water for ETAW, which results in a net agronomic quantity of 34.5 AF). Net agronomic use =34.5 af/year
Environmental Use	Small wetland and garter snake habitat maintained on field edges; plants assumed to use water like a grass hay such as Sudan, 4 AF/Y; approximately 5 acres of habitat	Habitat = 20 AF per year
Distributional Uniformity	Average low quarter applied water depth of a field relative to the average depth of water applied to the entire field for one irrigation event.	Average low quarter depth = 2.8 inches per irrigation event Average applied water depth = 3.8 inches per irrigation event
Field Scale Applied Water	Estimate provided by water supplier in monthly measured deliveries delivery is applied to the field. Field level groundwater pumping (10 af) and net change in surface storage and/or soil moisture (3 af).	400 AF AW per season [surface diversion is 375 af per season, 10 AF per season of private groundwater pumping 3 AF soil moisture in the field from previous season. For a total of 413 AF of AWf]
Equations:		
DU= Dawlq/Daw	={2.8/3.8} x 100= 74%	DU is an Indicator of water use efficiency but is reported here because it is generally done by on-farm irrigation evaluation.
CCUF= ETAW/(AW)	= {275/(413)} x 100=66%	Percentage of applied water used by field crops. 34% of applied water is non

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This example illustrates the earlier noted problem of water evaporation required for seed germination which happens BEFORE you start accounting for ETc. A hybrid tomato sprinkler/furrow field will take a bare minimum 4 inches and more like 6 to 8" to keep the seed hydrated and get the plants up. This is mostly lost evaporation from the bare wet soil! Was the 17 ac-ft supposed to cover this? This is only 1.6" and nowhere near enough. Why 1.6"? No earlier calculation methodology is offered. 4" is 41.7 ac-ft without any substantial leaching -- of course the rain in the Sacto Valley takes care of this -- which is certainly more than 0.24 effective feet.